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Overall Evaluation of Skylab (EREP) Images for

Cartographic Application

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Contents

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PREFACE

Multipurpose space missions such as Skylab are not compatible with the systematic sensing of the Earth. In spite of the time, efforts, and funds expanded on Skylab, the resulting Earth coverage is both spotty and non-uniform. Even if Skylab had been flown in a Sun-synchronous orbit, the coverage would still lack the consistency needed for cartographic application because of conflicting mission requirements. However, a mission such as Skylab does provide a platform from which a wide variety of Earth sensing experiments can be performed. Thus the cartographic significance of Skylab lies in the experimental employment and demonstration of remote sensors rather than in the sensor coverage.

The Earth sensing experiments have, in many cases, not been fully applied because of processing deficiencies. In spite of a published report to the contrary (18), several serious deficiencies in the processing of the data have been noted, specifically the reproduction of color image products and the entire processing procedure applied to the conical scanner (S192) data. Even so, Skylab has clearly demonstrated what sizable cameras and other sensors with suitable spatial and spectral resolution and geometric fidelity can accomplish from space.

SCOPE

Specific information about NASA's Skylab mission and the Earth sensing experiments conducted is given in various other documents. Principal

*Approved for publication by the Director, U.S. Geological Survey

references are the "Skylab Earth Resources Data Catalog" (1a) and the "Earth Resources Production Processing Requirements for EREP Electronic Sensor" (1b).

This report is interim because suitable data from the multispectral conical scanner (experiment S-192) was delayed in delivery and is yet to be fully analyzed. In all other respects, the report is final. It is a summary because it depends on the detailed analyses of others. The results of available analyses conducted outside, as well as within the U.S. Geological Survey (USGS) have been evaluated and included. Experiments and analyses summarized are as follows:

- National Aeronautics and Space Administration (NASA) experiment 496, conducted by Joseph T. Pilonero, USGS, "Photomapping of the United States" (2).

- NASA experiment 496B, conducted by Jack Staples, Defense Mapping Agency/Inter American Geodetic Survey (IAGS), "Cartographic Experiment for Latin America" (3).

- NASA experiment 499, conducted by William J. Kosco, USGS, "Map Revision of line maps at 1:250,000 to 1:5,000,000 scale" (4).

- NASA experiment 501, conducted by Dean T. Edson and Doyle G. Smith, USGS, "Thematic Mapping of snow, water, IR reflective vegetation and massed cultural features " (5).

- NASA experiment 497, conducted by John D. McLaurin and William Schoonmaker, USGS, "Cartographic Evaluation of Experiment S192" (6).

- Resolution analyses by Roy Welch, University of Georgia and consultant to USGS (7).

- Report by the Cartography Department, Defense Mapping Agency Aerospace Center, "Photo Revision of Large-Scale Maps Using Skylab Photographs" (8).

- Canadian Skylab experiment reported by R.A. Stewart in "Mapping from Satellite Photography" and presented at the Commonwealth Survey Officers Conference 1975 (9).

- Paper by Rigdon E. Joosten, NASA, "Cartographic Investigations from Skylab" (10).

- NASA experiment 459, conducted by Morton Keller, National Ocean Survey (NOS), "Analytical Triangulation Utilizing Skylab Earth Terrain Camera (S-190B) Photography" (11).

- Hunting Surveys Ltd., Skylab experiment reported by Peter Mott in the proceedings of the 1975 Fall Convention, ACSM (23).

- Pertinent results reported in the NTIS weekly abstract of NASA Earth Resources Survey Program (12).

- Presentations of the IAGS Skylab investigators' seminar, Canal Zone, June 25-27, 1975, reported by Frederick J. Doyle, USGS.

- Various evaluations of the S-190B experiment reported by John D. McLaurin, USGS, Department of the Interior coordinator for the experiment.

SPECIFIC EXPERIMENTS

General

Skylab carried three experiments of direct cartographic interest. Two were frame film cameras (S-190A & S-190B), and the third was a conical scanner. In general, the film cameras performed as expected and provided photographs which, though widely scattered, demonstrated the basic capabilities of frame film cameras in space for various cartographic applications. Not only the cameras but various black-and-white, color, and color infrared films with cartographic application were also successfully demonstrated. The third experiment (S-192), the conical scanner, provided some cartographically significant results in spectral bands beyond those in common use. It also demonstrated a new concept in imaging geometry which could have considerable cartographic significance. However, data processing complications have, to date, precluded definitive evaluation of the S-192 experiment. Based on a nominal altitude of 435 km, the three experiments produced strips of imagery of the following approximate ground swath (width):

- S-190A - 163 km
- S-190B - 109 km
- S-192 - 70 km

Thus, for cartographers to whom coverage is paramount, the listing indicates an order of priority. Cartographic results are described according to the three experiments in the following sections.

S-190A

This experiment consisted of a group of six multispectral, commonly boresighted, frame film cameras built by Itek Corporation. The cameras were of 6-inch (152.4 mm) focal length and recorded on 70 mm film in a 57.2 mm square format. Four wavebands, green (0.5 to 0.6 μm), red (0.6 to 0.7 μm), and two near infrared (0.7 to 0.8 & 0.8 to 0.9 μm) were recorded on black-and-white film; the other two cameras exposed color (0.4 to 0.7 μm) and color infrared (0.5 to 0.88 μm) films. All six film records were exposed simultaneously. From the nominal altitude of 435 km the photograph scale was 1:2,850,000.

Spatial and spectral resolution. NASA (1 a,b,c) reports optical resolution as high as 90 line pairs per millimetre (lp/mm) in the red band at high (6:1) contrast. However, tests conducted by Welch (7a) on the best imagery received (second generation) gave an estimated resolution of only 50 lp/mm at low (1.6:1) contrast (7), equivalent to about 60 m on the ground from the nominal altitude of 435 km. Such resolution permits the identification of major cultural features of reasonably high contrast. It does not, however, show some important features, such as railroads, secondary roads, or urban boundaries, to the extent that they can be identified with sufficient confidence for map revision (3, 4, 9). In order to achieve 1:250,000 scale, a 11.4 enlargement is necessary, reducing the resolution to less than 5 lp/mm. The unaided normal human eye can see detail as fine as 5 lp/mm, so there is little advantage in enlarging beyond 1:250,000 scale. Other evaluations (1, 2), also indicate that 1:250,000 is the largest suitable scale for general-purpose

image presentation of S-190A photographs. Color and color infrared films have lower resolution (7 a, b) and, for general use, should be presented in image form at maximum scales somewhat smaller than 1:250,000.

Resolution of color images was greatly affected by processing. A copy of high-resolution color film is inevitably degraded unless it is made through an enlarger rather than by contact, the method generally used by NASA. The problem was even more severe in the S-190B experiment, where it is discussed in more detail.

In theory, the S-190A experiment could have shown the water penetration capabilities of the blue (0.4 to 0.5 μm) band as compared to the green (0.5 to 0.6 μm) band. Although the blue band was not covered by the black-and-white multispectral record, the difference in shallow water response should appear in a comparison of the color and color infrared film. Unfortunately the blue in color film such as SO 356 is the bottom layer, and transmission through the upper two layers degrades the blue record. In the Florida Keys project, only slight additional water penetration could be attributed to the blue band, probably because of the layering effect rather than basic spectral sensitivity (15).

As expected from analysis of previous space experiments with color photography, conventional color failed to add materially to information content except in desert areas of very clear air. Nevertheless, some cartographers preferred to use color film despite its somewhat lower resolution as compared with black-and-white (9). Color infrared film was found, as expected, to record vegetation distribution far more effectively than any single black-and-white or conventional color record. However, the color portrayal of S-190A data obtained by combining two black-and-white records is considered far more

effective than that obtained from color or color infrared film. By combining the response of station 5 (red) with station 2 (infrared), a high-quality color infrared portrayal of Connecticut at 1:250,000 scale was obtained by Pilonero. It is significant that the black-and-white infrared film was rated at only 20 lp/mm (7) and that the new high-resolution black-and-white infrared film such as Kodak SO 289 should provide considerable improvement. The multispectral aspects of this experiment are also considered significant cartographically in that they readily permit thematic extraction by photographic means (5). USGS has isolated water and vegetation and to a lesser extent the urban areas of the Hartford quadrangle. However, the resulting product has not as yet been published.

<u>Geometric fidelity</u>. The S-190A experiment confirmed the geometric fidelity expected of a good mapping camera. Since base/height ratios are very small, topographic compilation was limited. However, planimetry was compiled directly at 1:250,000 scale from a single image with satisfactory accuracy; from a stereomodel, standards equal to 1:50,000 scale (Class B NATO Standards) were achieved for planimetry (9). Aerial triangulation perhaps compatible with 1:250,000-scale mapping was also demonstrated (9). Mott (23) did report a 250 m contour interval compilation capability, which is significant considering the small base/height ratio of 1:7. The high geometric fidelity is also significant in that records of the same scene but from different cameras were superimposed with high precision.

Products. A wide variety of cartographic products resulted from the S-190A experiment as follows:

- Image maps at scales ranging from 1:250,000 to 1:100,000 (2, 3, 9, & 10).
- Revision of selected features on line maps at scales as large as 1:50,000. The limiting scale was determined by the accuracy with which the features to be revised can be transferred from the image to the map manuscript (4, 8, & 9).
- A line map compiled with 250 m contours at 1:500,000 scale, with a small portion compiled at 1:62,500, in Nepal (23). The accuracy of the compilations is unknown.
- Thematic extraction by photographic methods of open water, and snow and ice. Vegetation, wetlands, and urban areas were also photographically extracted but not to the same degree as water or snow and ice (5). With visual interpretation, the number of themes isolated is extensive, largely because of the multispectral nature of the experiment.

S-190B

This experiment involved a large frame camera of 18-inch (457 mm) focal length recording on a 4.5-inch (115 mm) square format. It was called the Earth Terrain Camera (ETC) and was built by Actron Industries, Inc. Black-and-white, color, and color infrared films were exposed. From the nominal altitude of 435 km, the contact scale was 1:950,000. Pertinent results are as follows:

Spatial and spectral resolution. On high-resolution black-and-white film, the camera recorded 60 to 70 lp/mm at low (1.6:1) contrast; 70 lp/mm

is equivalent to 15 m on the ground (7c). At that resolution, a large variety of cultural features can be detected and to a certain extent identified. However, some features critical to map revision, such as railroads, roads, and other features of poor contrast, could not be properly identified (3, 4, 8, 9, & 23). Features successfully identified could be plotted with acceptable accuracy (U.S. National Map Accuracy Standards) at scales as large as 1:24,000 through spatial reference to other properly mapped nearby features (8). However, 1:50,000 was the largest scale generally used for S-190B revision (3 & 9). It is significant that a noncartographic Skylab investigator also reported that some roads, even though 10 m wide, could not be detected due to low contrast (12). At 9.5 enlargement S-190B imagery is at nominal 1:100,000 scale with a maximum resolution of 7 lp/mm. This, again, is the approximate limit of the human eye. For lower resolution films, optimum scale is something smaller than 1:100,000. It is significant to note the large difference in spatial resolution that results from different image processing. From high-resolution black-and-white originals, investigators generally received copies that retained the original resolution. The enlarged S-190B image of MacDill Air Force Base in Florida as published by the National Geographic Magazine (13), is an example of good image processing. On the other hand, copies of high-resolution color film (SO-242) received by investigators were generally degraded. USGS did obtain an enlargement direct from the original of an S-190B image of St. Louis, which was published at 1:100,000 scale in Photogrammetric Engineering (14). However, NASA (Johnson Space Center) published the same image at 1:50,000 in the Skylab Data Catalog (1, p. 66),

apparently after being contact copied in color from the original with a sizable resolution loss, which may be expected because color duplicating film does not have the required resolution (7c). Even allowing for the difference in scale, it is obvious that the <u>Photogrammetric Engineering</u> version is far superior to the NASA catalog version, which represents the quality of Skylab color imagery generally supplied to investigators. In the copies of the high-resolution color infrared film (SO-131) made for investigators, serious differences also resulted from the enlargers used by NASA. The copies received by USGS indicate that the 2x enlarged version retain original resolution whereas 4x enlargements are degraded (7c).

The multispectral aspects of the S-190B experiment were severely limited by the single camera employed. Separate waveband records could only be made by selective filtering of the color or color infrared response. Cartographic experimenters, employing the multispectral approach, including theme extractions, generally preferred the S-190A images.

<u>Geometric fidelity</u>. The S-190B camera was not designed for cartographic use. It has a shutter in the focal plane rather than between the lens, fiducial marks are lacking in the camera body, and image-motion compensation was obtained by rocking the camera. However, since the camera had a very narrow field of view (14.24° across the flats), the cartographic deficiencies did not appear to be significant except in the case noted by Mott (23) which involved the extreme relief of the Himalayas. As in the S-190A experiment, the narrow field of view limits topographic compilation. As previously indicated, some local revision was successful at a scale as large as 1:24,000,

but resolution is the controlling factor rather than geometric fidelity. The largest scale at which the experiment has had general cartographic application with acceptable accuracy is 1:50,000.

Products. Cartographic products resulting from the S-190B experiment are summarized as follows:

- Image maps at scales as large as 1:50,000 (2, 3, 7c, 9 & 10).
- Line-map revision of selected features at scales as large as 1:24,000.
- One topographic (contour) map was attempted (Paraguay) with convergent coverage from a strip of S-190A photographs and a strip of S-190B photographs taken on different orbits, but the results were inconclusive (3).
- Intermediate control was established by strip analytical aero-triangulation. In the United States under near ideal conditions of low relief, accuracy was adequate for compilation of a planimetric map of about 1:165,000 scale at U.S. Map Accuracy Standards (11). In the Himalayas, Mott (23) reports results of about half this accuracy (twice the errors).
- Various thematic maps were prepared through the use of human interpretation, but no examples of photographic (autographic) theme extraction were noted.

S-192

This experiment is potentially the most significant for cartographic research because it demonstrated a new form of image acquisition through a conical scanner, and because it recorded certain waveband signals from the Earth seen for the first time from space. Technical problems, both in acquiring and processing data, have so far precluded full evaluation of the

experiment or preparation of significant products. However, investigations to date (some of them mine) warrant the following observations.

Spatial and Spectral resolution. The S-192 picture element (pixel) records the same size area on the Earth (80-m square) as the MSS on Landsat-1 & -2. To date, the only imagery examined in detail had been resampled into linear form. Resampling involves some degradation so that the effective resolution of the original data has not been properly assessed. However, even on the resampled linearized image, the resolution of cultural features in certain bands, such as 4, 5, and 11 (see following tabulation), compared favorably with Landsat resolution of band 5 (0.6 to 0.7 μm). This result may, in part, be due to the redundancy in sampling that occurs as one moves off the orbital path.

The conical scanner records a 110° arc (55° on either side of the sub-orbital track), and at the 55° maximum off-track position the redundancy is about 43 percent in one direction, radial from the nadir. The percentage of redundancy varies as $1 - \cos \alpha$ (α is the scanning angle off the orbital track). Redundancy does increase the effective resolution but not to the full extent indicated by the percentage of redundancy. However, the net pixel size is reduced by $\cos \alpha$, and thus at 55° off the orbital track the net pixel dimension is about 79 by 45 m as compared with 79 by 79 m along the orbital path. This compares with 79 by 56 m as the net Landsat pixel. It is assumed that scanning rates are synchronized with the velocity vector so that adjacent scans along the orbital path form tangent pixels.

Spectral resolution of the S-192 scanner is defined by the following tabulation (1b):

Band No.	Wavelength* (micrometers)	Channels (1b)
1	0.41 - 0.46	22
2	0.46 - 0.51	18
3	0.52 - 0.56	1-2
4	0.56 - 0.61	3-4
5	0.62 - 0.67	5-6
6	0.68 - 0.76	7-8
7	0.78 - 0.88	9-10
8	0.98 - 1.08	19
9	1.09 - 1.19	20
10	1.20 - 1.30	17
11	1.55 - 1.75	11-12
12	2.10 - 2.35	13-14
13	10.20 -12.50	15-16-21

It is unfortunate that S-192 data as distributed by NASA (JSC) are referenced to channels rather than bands, and the tabulated relationship must be fully understood to avoid misunderstanding. Several items of cartographic importance have been noted due to spectral resolution as follows:

- Band 3 (0.52 to 0.56 μm) as reported by Polcyn (16) has water penetration superior to Landsat band 4 (0.5 to 0.6 μm). Polcyn attributes the effect to the narrower band. In theory, band 2 (0.46 to 0.51 μm) should show even greater penetration in truly clear water, but no results of such a comparision are available.

- I (17) examined S-192 data of the Baltimore/Delmarva Peninsula area on the GE 100 digital image processor. Doyle Smith (19) likewise examined hard-copy transparencies of the same area. Points noted:

1. Band 11 (1.55 to 1.75 μm) provides good contrast with cultural features,

*These wavelengths differ from those published in the Skylab Earth Resources Data Catalog (1a) which, according to the NASA experiment monitor, Rigdon Joosten, are in error.

vegetation, and water bodies, thus providing an overall better monochromatic response of Earth surface features than can be obtained in one visible or shorter infrared waveband as used by Landsat. The same contrast seems to carry into band 12 (2.10 to 2.35 μm); however, the band contained too much noise for full evaluation.

2. Thin cloud and haze penetration, noted before in the near infrared, appeared to be about optimum in band 11 with no apparent increase in band 12.

3. Other responses noted were generally in keeping with results obtained from other aircraft and spacecraft multispectral experiments.

- Investigations of the Florida Green Swamp by Coker et al. (21), indicate that no less than 9 subcategories of ground cover could be delineated with reasonable high accuracy, demonstrating the importance of the multispectral approach to cartography as well as other disciplines.

Geometric fidelity. The internal geometry of a conical scanner is simplicity itself and in many ways ideal for cartographic presentations. Obviously an imaging device that properly reconstructs the conical sweep is essential to processing of S-192 data, geometric analysis, and application. However, processed data have not yet been supplied in a form suitable for analysis.

If we assume that external geometric conditions, such as altitude, attitude, relief, and spacecraft velocity, are fixed and uniform, the continuous image is defined by a simple cylindrical projection of near-zero distortion. This cylindrical projection may be perspective, equidistant (Cassini), or conformal, depending on how the imaging device modulates the pixels in the

cross-track direction. However, the differences are so small that for practical purposes they can be ignored. Cartographically, an appropriate conformal projection is the Space Oblique Mercator (20). On this projection, S-192 imagery has scale distortion due to the projection of less than 1:50,000 and for all practical purposes is distortion-free.

A conical scanner has some fundamental geometric advantages over line scanners and photographic imaging systems. Mechanically the constant rotational motion is highly desirable, but the constant aspect angle to the figure of the Earth may be even more significant. The optical scanner is fixed at 5°32' off the nadir (assuming true verticality of the sensor element), thus every element of the Earth's surface figure is imaged at 5°55' off the vertical, since 23' of Earth curvature is also included. Moreover, relief displacement is constant at about 10 percent (0.10363) of the elevation differences and always radial from the nadir (center of scanner arc). Solar illumination will of course vary; but having the aspect angle fixed and constant will simplify any geometric transformation of the data. Moreover, the constant aspect angle is also important for sensing vegetation, particularly row crops, where changes in aspect angle significantly change the spectral return. This condition is obvious in aircraft imagery but also significant for lower resolution space imagery as well. The disadvantage lies in the current lack of equipment and procedures for properly processing conical scan data. Moreover, digital image data sets are generally based on linear (x,y) coordinate systems, and correlating conical scan data with linear data are impractical unless the conical data are resampled into linear form. Nevertheless

the conical scanner promises to be competitive with remote sensors now in common use.

Products. Some spectacular multispectral S-192 imagery has been published but to date products of cartographic value have not been recognized.

CONCLUSIONS

- The report by Mott of Hunting Surveys Ltd. (23) established a good case for covering the unmapped areas of the world with photographs from space with resolution comparable to that of the S-190B experiment. Such resolution in proper geometric form would be recorded by a relatively wide-angle frame camera of 12" (305 mm) focal length carried at altitudes of 200 to 250 km. Such coverage has previously been recommended to NASA by the Interior Department in 1970 (24). Mott's report reinforces Interior's position with the conclusion that this coverage is still required. However, once suitable coverage is obtained for topographic mapping, coverage need not be repeated (except on a local basis) because topography is basically static. Planimetry, which is changeable, can best be recorded by near-orthographic systems rather than a wide-angle frame film camera.

- Film cameras used in experiments S-190A and S-190B performed as predicted. Thus cartographic camera systems for space will likely perform as expected.

- The multispectral aspects of remote sensing of the Earth have not been adequately investigated for cartographic and related applications.

- The conical scanner experiment S-192 should be further investigated. The data should be printed in hard copy by a conical recorder and subjected to proper resolution, geometric, and spectral analyses. Enhancement techniques

such as those applied to digital image data of the planets (& Landsat) should also be applied to important segments of the S-192 data.

- Processing of data from any remote sensing flight should be engineered and executed so as to preserve the original information content. Adequate processing was lacking in Skylab data.

- For effective cartographic application, a space flight should be dedicated. Since cartography supports a wide range of Earth science disciplines, the imagery from a dedicated flight has wide application. The flight should be automated insofar as possible, including the processing of data into cartographic form.

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